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# COMPARISON OF FULL-SCALE AND MODEL BUFFET RESPONSE OF APOLLO BOILERPLATE SERVICE MODULE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## SUMMARY

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Some preliminary results are presented to compare the high-frequency local buffet responses obtained in the actual flight of the Saturn-Apollo 7 with the responses predicted by an aeroelastic-model technique for the boilerplate Apollo service module. Data are presented in the Mach number range from 0.30 to 1.30. Although some disparities are noted in the data, the general results indicate that the use of aeroelastic models as tools to predict high-frequency local buffet response of full-scale structures is a promising technique.

Author

## INTRODUCTION

For the past several years a concerted research effort at the Langley Research Center has been directed toward the development of techniques to be used to predict the buffet response of launch-vehicle structures. Launch-vehicle buffet response may be divided into two general categories; namely, low-frequency gross bending response and high-frequency local response. These two types of response are illustrated in figure 1. Most of the emphasis has thus far been placed on the low-frequency gross bending response of the entire vehicle. One technique which appears quite promising is the aeroelastic-model approach. (See refs. 1 and 2.) This method may be summarized as follows: A dynamically scaled aeroelastic model is constructed; the model is tested in a suitable wind tunnel; and the buffet response is measured. The model data are then scaled to full-scale values by use of the appropriate scaling laws.

Recently, attention has been turning from low-frequency bending response to the more complicated problem of high-frequency local response. On the basis of experience gained by using the aeroelastic-model approach in studying low-frequency buffet, an extension of this same type of procedure to the high-frequency problem seemed only

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natural. The purpose of this study is to present some preliminary results from an application of this model approach to the high-frequency local buffet response of the boiler-plate version of the Apollo service module in the Mach number range from about 0.30 to 1.30. Data are presented in terms of the response of the actual Saturn-Apollo 7 (SA-7) and the response predicted on the basis of the aeroelastic-model technique. For this application a special aeroelastic model was used, namely, a 1/10-scale structural replica. A true structural replica is identical to the full-scale structure in all respects except that linear dimensions have been reduced by the scale factor.

## CONFIGURATION

A photograph of the SA-7 launch configuration is shown in figure 2. The part of the structure of interest in the present investigation is representative of the connecter section that joins the Apollo command module to the Saturn upper stage. Figure 3 is a photograph of the model configuration mounted in the Langley 16-foot transonic tunnel. The model may be conveniently divided into three sections, a rigid command module and launch-escape system, a rigid booster upper stage, and the structural replica of the connecter section. The structural replica portion was composed of three sections as is shown in figure 4. These sections, the service module, the insert, and the adapter, are of semi-monocoque construction. The rigid parts of the model were attached to the wind-tunnel sting. The service module was connected to the command module in a fashion similar to that used on the full-scale structure. The downstream end of the structural replica portion was attached to the sting through the instrumentation unit, which simulated the proper end restraint.

The location of the model instrumentation is also shown in figure 4. This instrumentation consisted of four lightweight crystal accelerometers and one miniature foil strain-gage bridge. The locations of these sensors were dictated by the placement of corresponding sensors on the actual flight structure. The accelerometers were sensitive to radial response, and the strain gage was sensitive to circumferential strain in a ring frame.

The degree to which it was possible to make the model an exact structural replica is illustrated in figure 5, which shows photographs of the structure at the upstream end of the service module for both the model and the full-scale vehicle. In the construction of the structural replica a few compromises were necessary. The major compromises were the use of formed parts in place of extrusions and variances in the rivet size and pattern. Another measure of the similitude between the model and full-scale structure is shown in figure 6, where the cumulative number of modes is plotted as a function of the full-scale frequency for both the model and full-scale structures. The slope of these curves is the modal density which is a significant parameter in the study of the response of complex structures to random inputs. (See ref. 3 for a discussion of the modal density concept.) The modal density is somewhat analogous to the normal mode concept used in low-frequency bending buffet response. Although the two sets of data differ somewhat in local detail, the general agreement in terms of the increase in number of natural resonances with increasing frequency is good.

## WIND TUNNEL

The Langley 16-foot transonic tunnel was used in the present investigation. A comparison of the variation of flight and wind-tunnel dynamic pressure with Mach number is presented in figure 7. In general, the flight dynamic pressure was about 20 percent lower than the corresponding wind-tunnel value. Ideally, the wind-tunnel dynamic pressure should be exactly equal to the flight dynamic pressure. However, from a practical point of view it is often difficult to find an available wind tunnel which provides exactly the required dynamic pressure and which has a test section sufficiently large to permit selection of a reasonable geometric scale factor of the model. Differences in dynamic pressure can be accounted for by using the appropriate scaling law.

## RESULTS AND DISCUSSION

The results of the model investigation are presented in terms of a comparison of model data scaled to full-scale values with data obtained from the SA-7 flight. For the purposes of scaling the model data, it was necessary to take into account the effects of geometric scale factor, dynamic pressure, structural damping, and accelerometer loading. Accelerometer loading is the effect of the nonscaled accelerometer mass on the local structural response of the model. It was assumed that aerodynamic damping effects were negligible. The comparison is made both in terms of distribution of response with frequency (power spectral density) and in terms of the variation of root-mean-square response with Mach number.

Presented in figure 8 is a comparison of model and full-scale strain power spectral densities (PSD). The power spectral densities have been normalized by the overall mean-square strain. As is shown by the data in the figure, the general agreement between the two densities is good.

Figure 9 provides data for a comparison of the variation with Mach number of the root-mean-square (rms) strain. These two variations do not show the same good agreement that was found in the comparison of the power spectral densities. In general the variations of rms strain with Mach number show similar trends; that is, they increase in value up to a maximum at a Mach number of about 0.85 and then decrease with increasing Mach number. The discrepancy between the magnitudes of the full-scale and model data might be very disconcerting except that these strains are at a very low level. The maximum root-mean-square strain measured in flight would correspond to a root-mean-square stress of only about 300 pounds per square inch. The maximum model root-mean-square stress would be about 120 pounds per square inch. It is indeed difficult to measure such small strains accurately under flight and wind-tunnel test conditions. In both cases the level of the maximum root-mean-square data was only about 5 percent of the instrumentation range. It is believed that a large part of the difference in magnitude between the root-mean-square strain data may be due to experimental error.

Presented in figure 10 are two typical accelerometer power spectral densities, one from model data and one from flight data. These power spectral densities have also been normalized by the overall mean-square values. As is seen from the data in figure 10, most of the energy for both sets of data is concentrated in a relatively narrow band of frequency about 100 cps wide. However, this band for the model is centered at a different frequency from that of the SA-7 flight vehicle.

The data in figure 11 show the variation with Mach number of the service-module root-mean-square acceleration. The data are presented in terms of bands which encompass the accelerations of the three service-module accelerometers. The agreement between the two sets of data is good. They both exhibit essentially the same variation with Mach number and have for all practical purposes the same level. Had the adapter acceleration data (at a different longitudinal station, see fig. 4) been included in these data, it would have essentially resulted in a slight decrease in the lower values of both bands.

## CONCLUDING REMARKS

Some preliminary results have been presented to compare actual flight Saturn-Apollo 7 high-frequency local buffet responses with aeroelastic-model-predicted responses of the boilerplate version of the Apollo service module. Although there are some disparities in the data, the general results indicate that the use of structural-replica models as tools to predict high-frequency local buffet response of full-scale structures is a promising technique.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 23, 1965.

## REFERENCES


1. Doggett, Robert V., Jr.; and Hanson, Perry W.: An Aeroelastic Model Approach for the Prediction of Buffet Bending Loads on Launch Vehicles. NASA TN D-2022, 1963.

2. Hanson, Perry W.; and Doggett, Robert V., Jr.: Aerodynamic Damping and Buffet Response of an Aeroelastic Model of the Saturn I Block II Launch Vehicle. NASA TN D-2713, 1965.

3. Dyer, Ira: Response of Space Vehicle Structures to Rocket Engine Noise. Random Vibration, vol. 2, Stephen H. Crandall, ed., The M.I.T. Press, 1963, pp. 177-194.

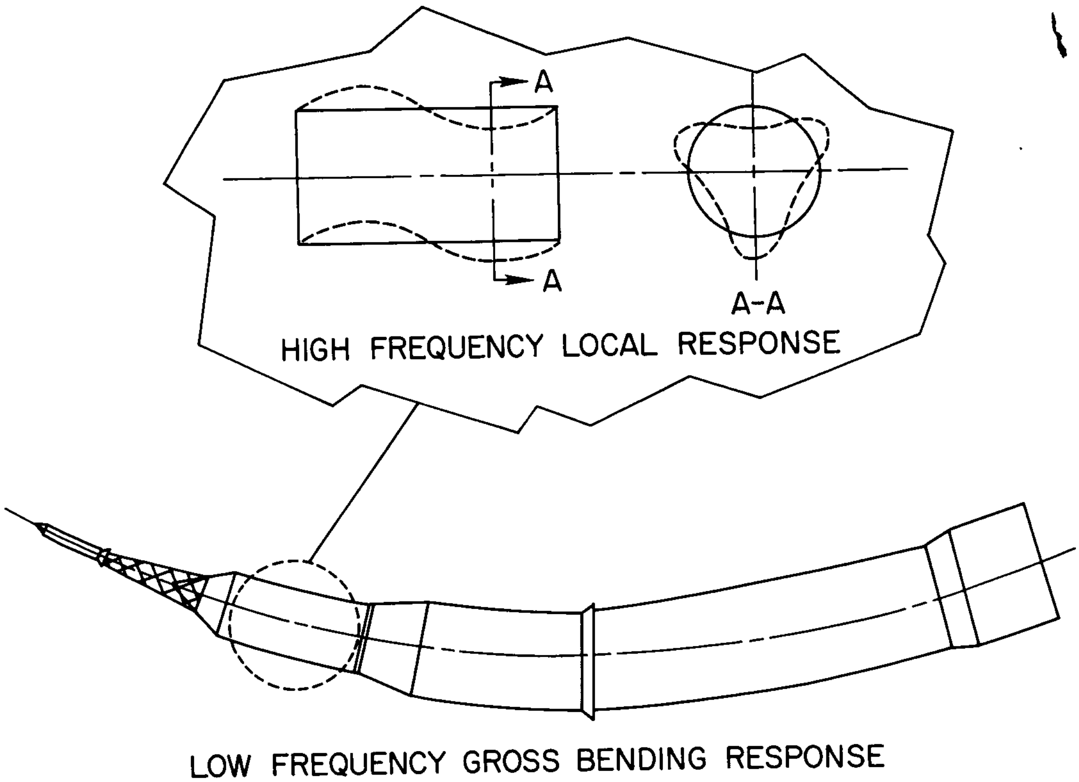



Figure 1.- Types of launch-vehicle structural response.

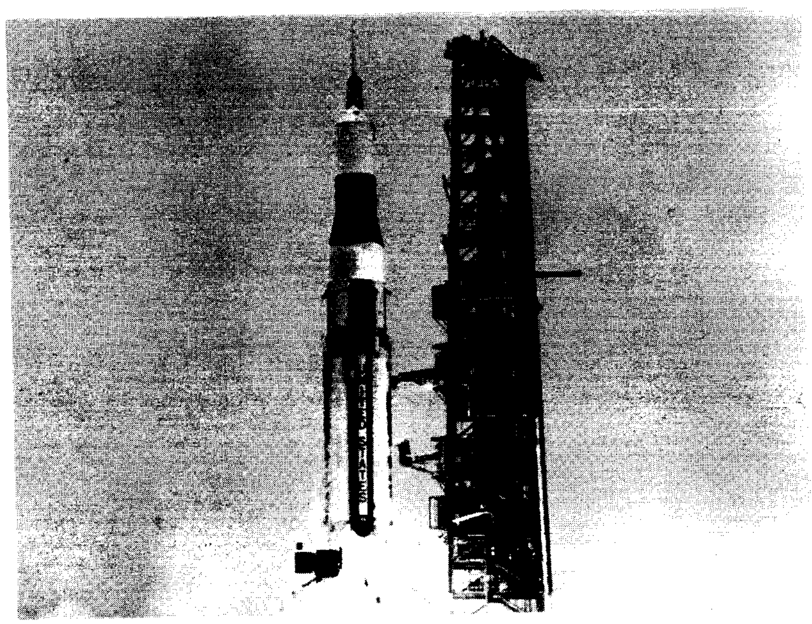


Figure 2.- SA-7 configuration. L-2473-1

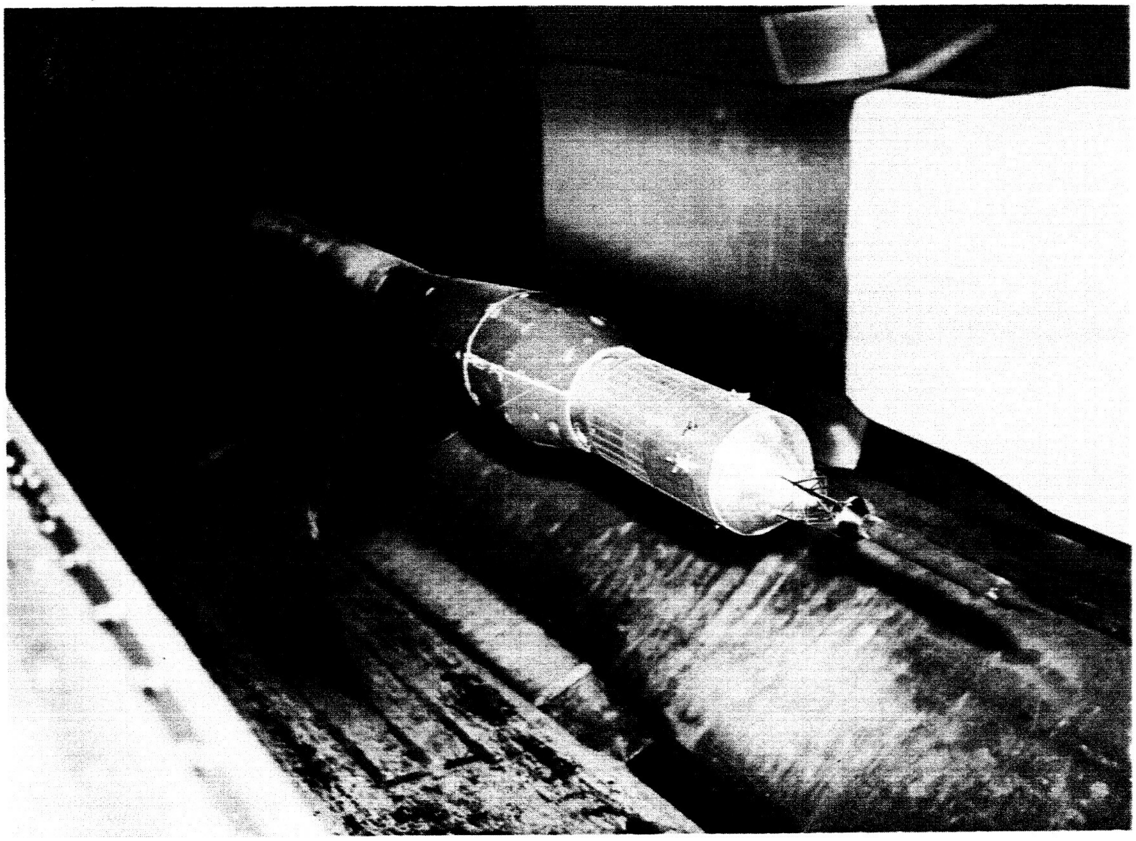


Figure 3.- Model mounted in wind tunnel. L-2473-2

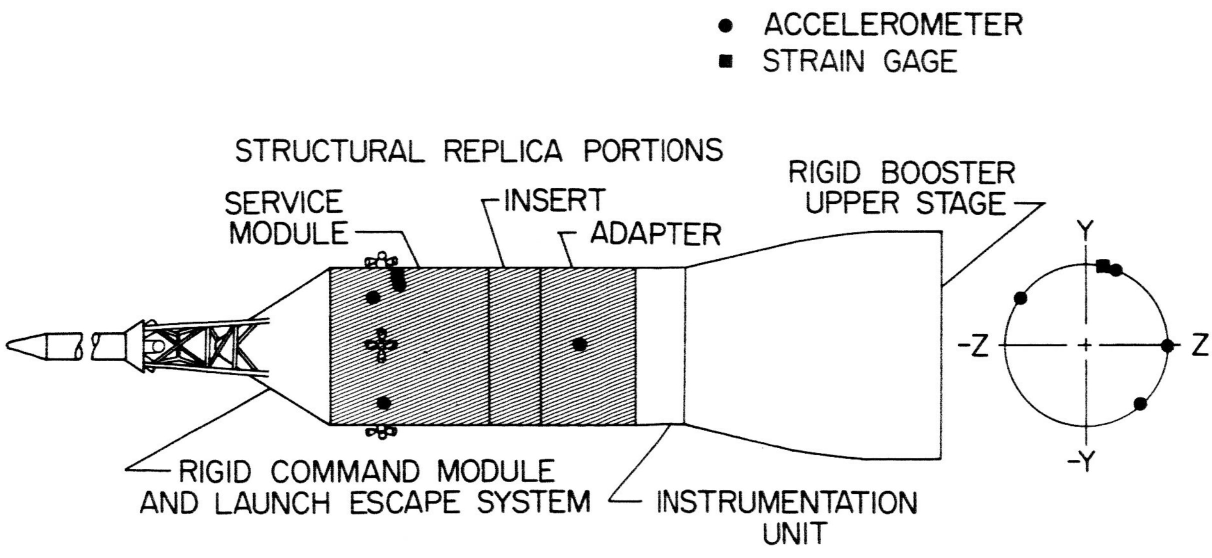
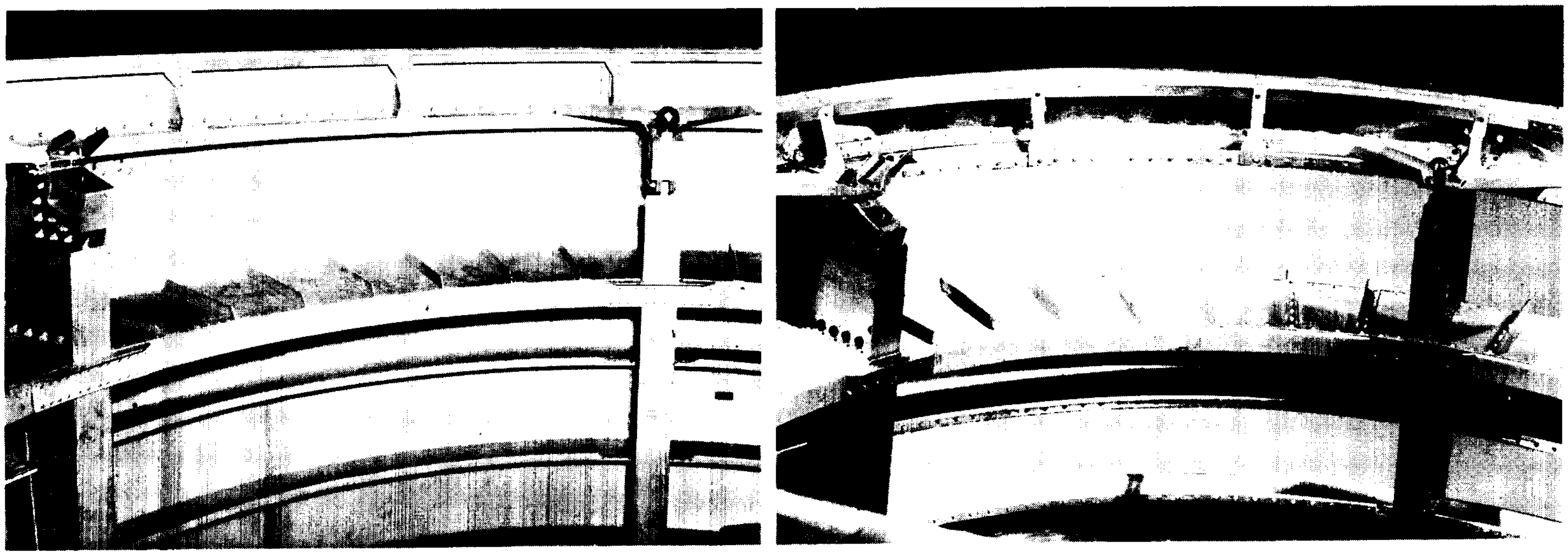



Figure 4.- Configuration and instrumentation.



FULL SCALE

MODEL

Figure 5.- Comparison of construction details.

L-2473-4

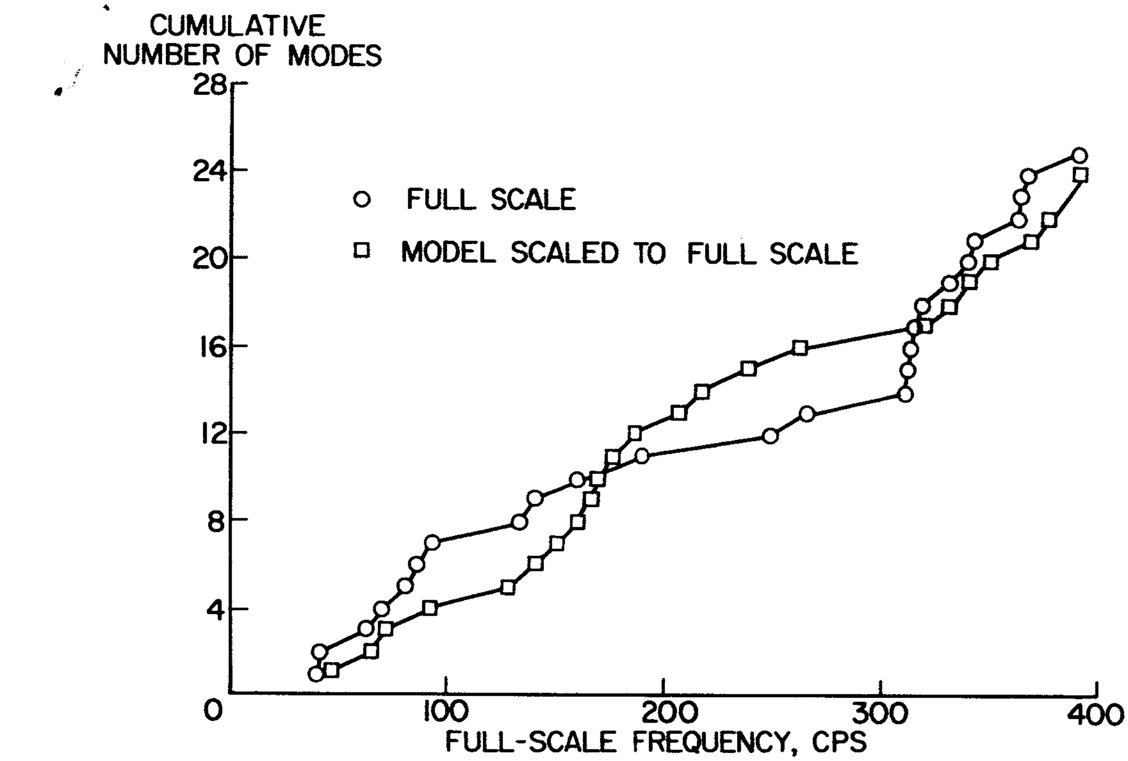



Figure 6.- Mode count.

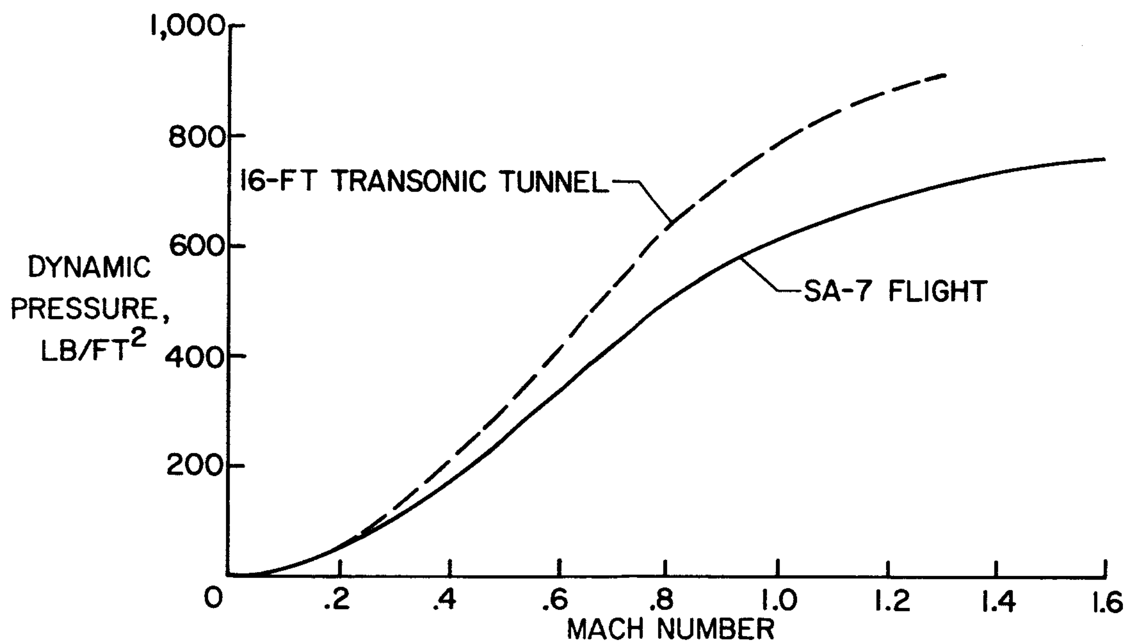



Figure 7.- Comparison of wind tunnel and flight dynamic pressure.

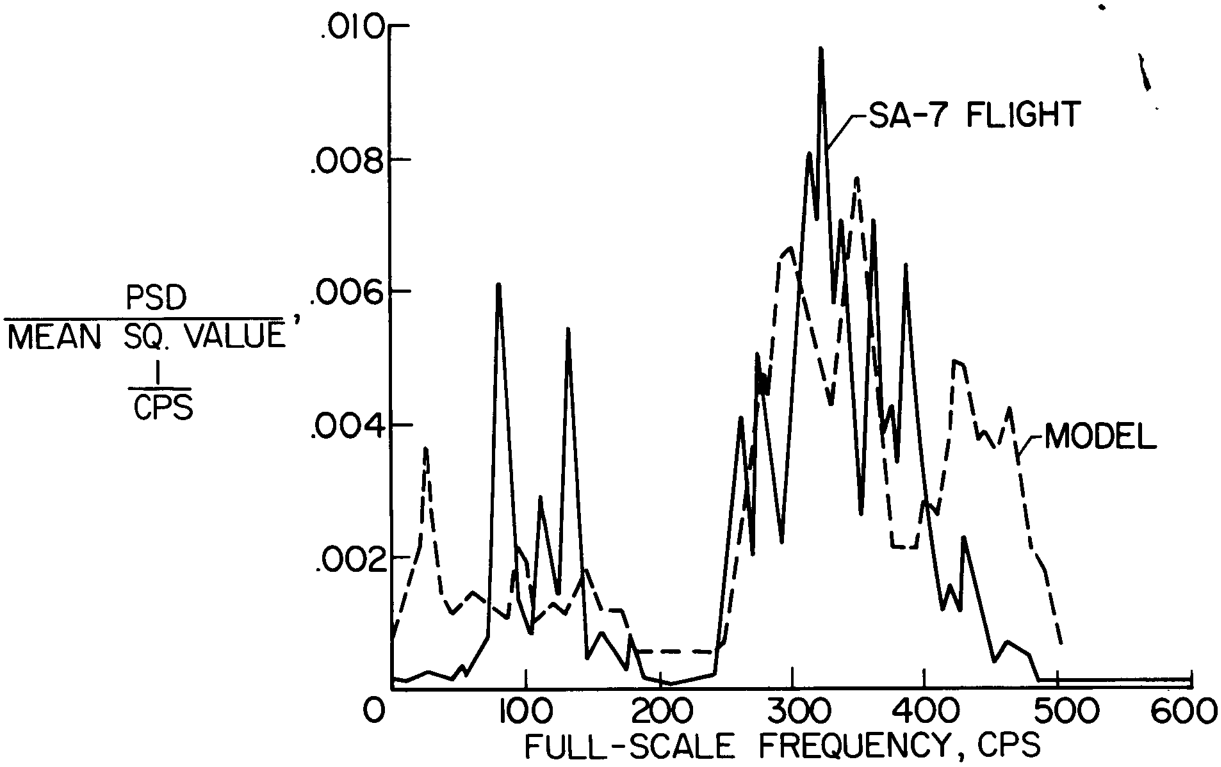



Figure 8.- Typical normalized strain-gage power spectral densities. Mach number = 0.80.

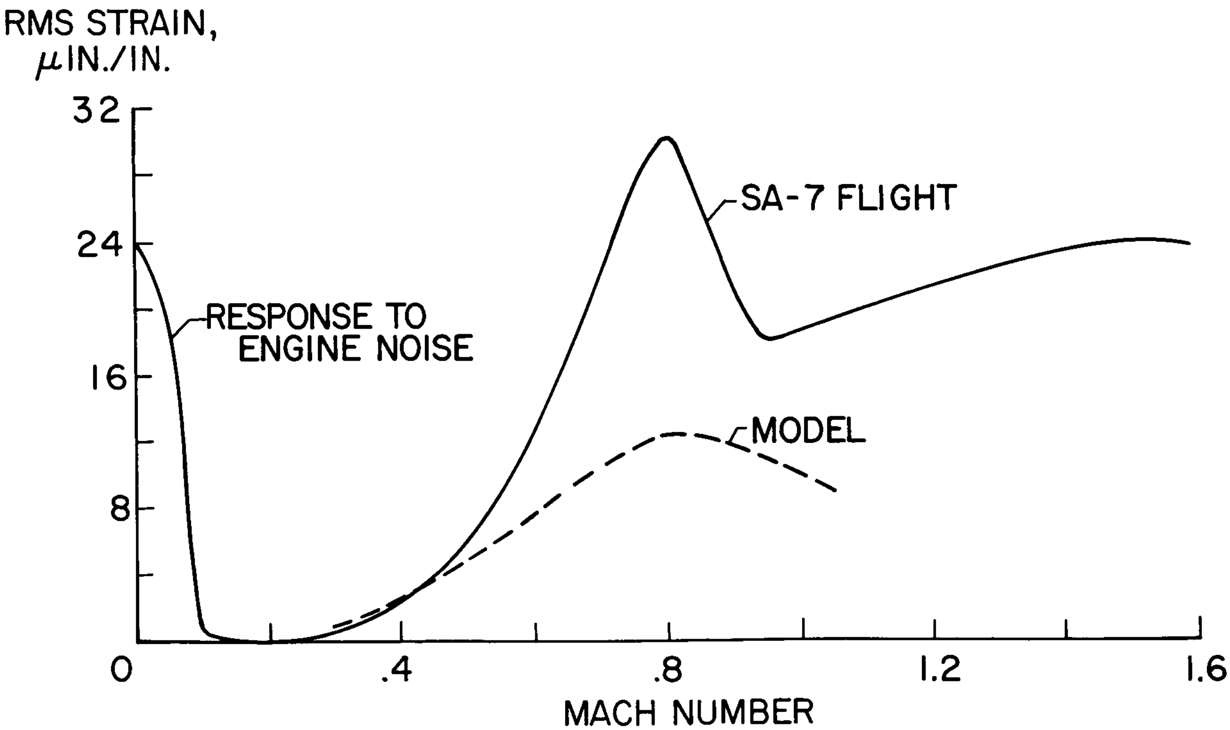



Figure 9.- Variation of rms strain with Mach number.

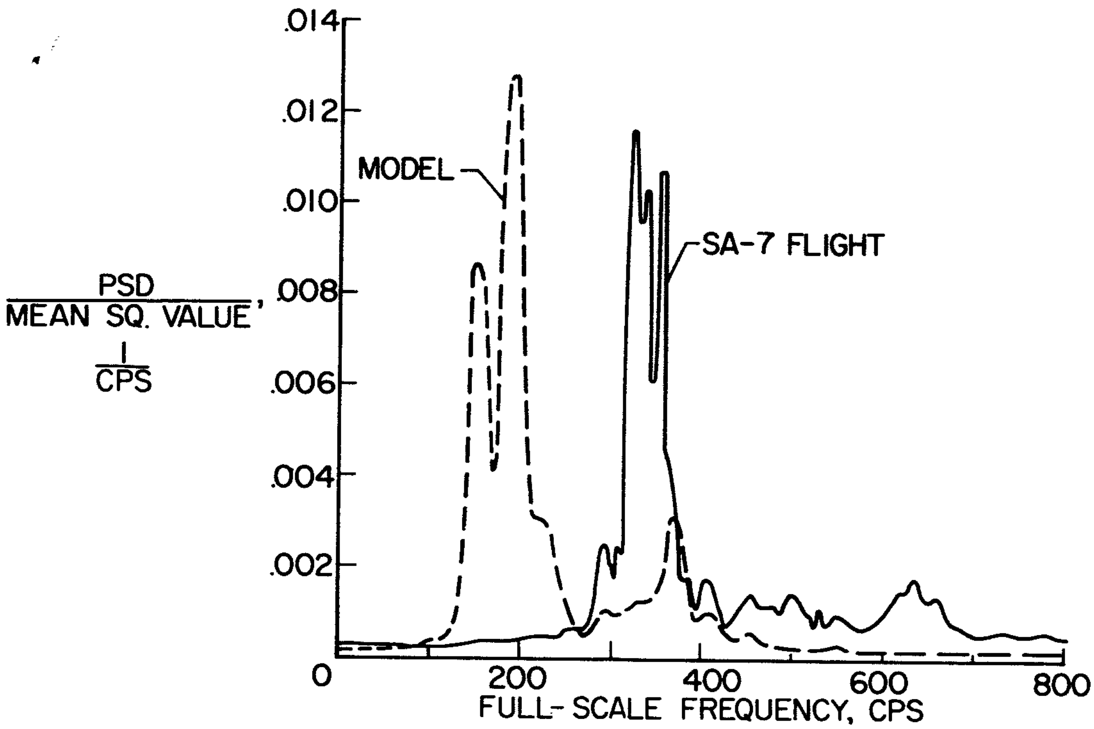



Figure 10.- Typical normalized accelerometer power spectral densities. Mach number = 0.80.

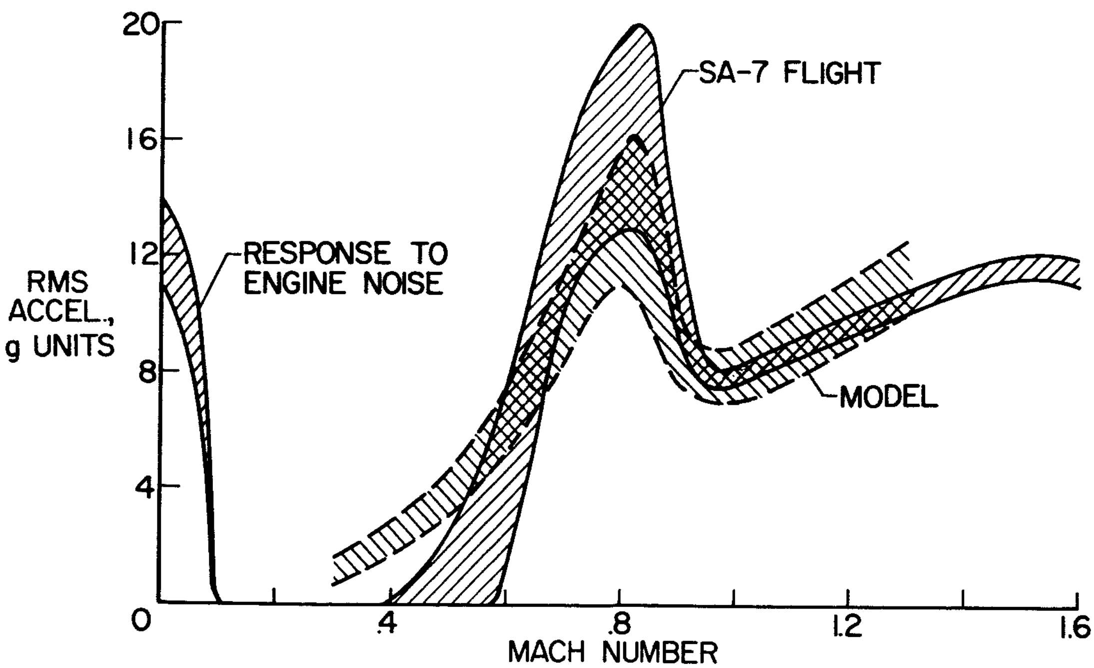



Figure 11.- Variation of rms acceleration with Mach number.